Inside the Zone of Proximal Development: Validating a Multifactor Model of Learning Potential With Gifted Students and Their Peers

Lannie Kanevsky & John Geake

Kanevsky (1995b) proposed a model of learning potential based on Vygotsky's (1978) notions of "good learning" and the zone of proximal development. This study investigated the contributions of general knowledge, information processing efficiency, and metacognition to differences in the learning potential of 5 gifted and 15 nongifted students. Traditional intelligence and achievement tests assessed students' knowledge; tests based on Luria's (1966) information processing model measured cognitive and metacognitive capacities; and learning potential was measured via dynamic assessments of student–tutor interactions while completing number patterns. Although the sample was small, the data supported the positions of Vygotsky, Luria, and Kanevsky on the complexity of learning potential, as well as the salience of internal functions and the social context while learning.

Introduction

Learning transforms innate capacities, prior skills, and knowledge into new understandings and accomplishments. It is something gifted individuals do extraordinarily well. The ease and enthusiasm with which they acquire such sophisticated understandings amazes and mystifies us. How do they do that? What is it about their learning that distinguishes them from their peers? How does this influence their development?

Much of the Western European and North American research has investigated ability-related differences in the products of learning by examining students' autonomous test performances. Their scores result from independent use of higher psychological functions, such as problem solving. In other words, Western researchers have focused on what Vygotsky (1978), a Russian psychologist, would have called the learner's current level of development.

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Activities that can be completed correctly without assistance indicate that the child has previously acquired the necessary knowledge and skills and that no new development was required to accomplish the task. For Vygotsky, this was an essential starting point for further development of these higher order psychological functions, not the end.

In contrast to Western interest in independent performance and completed development, Vygotsky (1978) stipulated that "The only ' good learning' is that which is in advance of development" (p. 89). Therefore, the psychological functions of interest in his work are those the child is ready to develop with help from others. These functions are on the verge of developing, but need support or scaffolding before the child will be able to use them independently. Once this occurs, the function is *at* the child's level of development, and new, more sophisticated functions become the focus of future development.

For Vygotsky (1978), as for all educators, the nature of good learning that leads development is most interesting, not the products of past learning. Participating in these episodes is exciting and informative, and Vygotsky's theory invites this. It asserts that good learning results from the progressive internalization of mental operations first experienced in social interactions with individuals who know how to complete more sophisticated tasks than a student could complete independently. Thus, "the transformation of an interpersonal process into an intrapersonal one is the result of a long series of developmental events" (pp. 56–57).

Vygotsky (1978) proposed a construct, the *zone of proximal development* (ZPD), to describe the types of experiences that exemplify good learning and lead development:

> It is the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers. . . .The ZPD defines those functions that have not yet matured but are in the process of maturation, functions that will mature tomorrow but are currently in an embryonic state. These functions could be termed the "buds" or "flowers" of development rather than the "fruits" of development. (p. 86)

Methods of assessing the ZPD in studies undertaken in the 1980s and 1990s (e.g., Brown & Ferrara, 1985; Day & Cordon, 1993; Kanevsky, 1990, 1994, 1995a) focused on tracking adult guidance in the student–tutor collaboration. Their findings indicated ability-

related differences in the breadth of the ZPD, as determined by the amount of assistance students needed to learn to solve difficult problems independently. Tallies of teacher support formed an index of learning potential. Students having greater learning potential and broader ZPDs needed less support.

In Vygotsky's original conception of the ZPD and in more current versions, learning potential is seen as rich and dynamic. It grows from a student's relationship with the tutor. Holzman (1997) provided one example of the enhanced dimensionality characteristic of more current conceptions.

> It [the ZPD] is not a zone at all, but the "life space" in which the so-called higher psychological processes in which human beings engage (such as speaking, thinking, and problem solving) emerge and develop. The critical feature of the ZPD as life space is that it is inseparable from the we who produce it. (p. 60)

This shift has direct consequences for models and methods attempting to explain and explore learning potential as represented by the ZPD. They must honor the relationships active in good learning contexts. Figure 1 presents Kanevsky's (1995b) model of learning potential and relationships among its components. Each shape represents a set of elements or factors. This model posits that learning potential results from the simultaneous contributions of all of the factors. Each will be described in the next section. (A comprehensive synthesis of the literature supporting the model can be found in Kanevsky, 1995b).

The intellectual and nonintellectual factors within the largest circle are characteristic of the learner. For example, knowledge, skills, and prior experiences stored in the student's general *knowledge base* provide the platform for scaffolding future development. Cognitive capacities involved with perceiving, storing, retrieving, and manipulating information are aspects of *information processing efficiency*. *Metacognitive knowledge and control* includes a learner's awareness of his or her thinking—skills related to planning and monitoring thinking and managing learning. These three dimensions of a learner's intellectual potential simultaneously interact with a range of nonintellectual factors related to what is to be learned, such as a student's interest, self-concept, and values.

In the past, conceptions of learning potential ended here, as if it lived solely within the individual. However, consistent with a Vygotskian orientation, we believe it is influenced by features in the learning environment, including the learner's relationship with

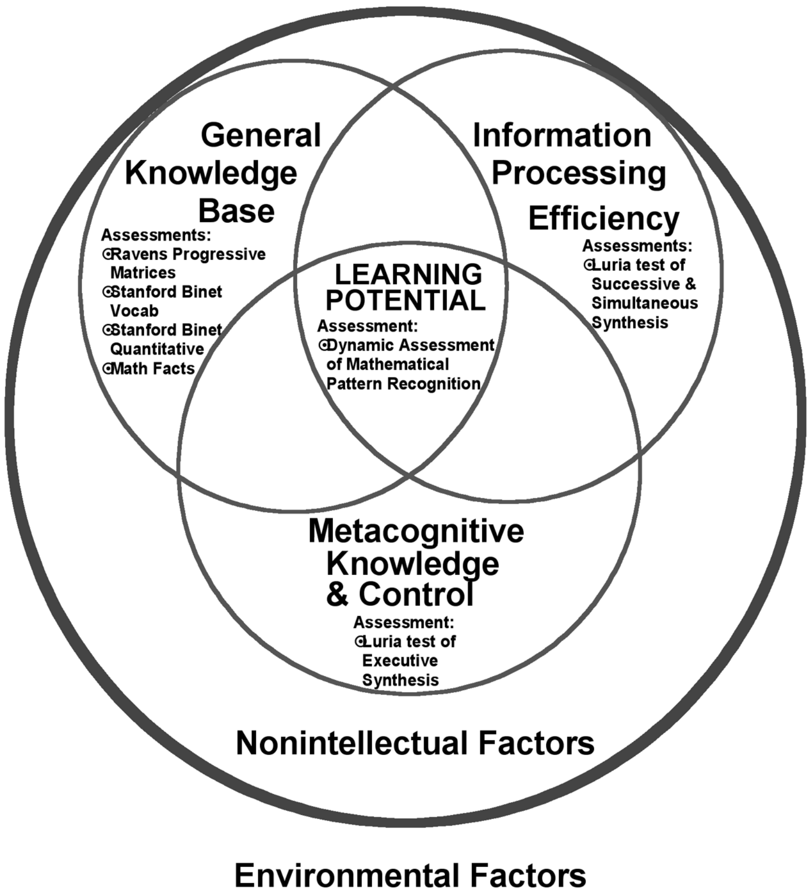

Figure 1. Interdependent factors contributing to individual differences in learning potential (Kanevsky, 1995b) and assessment methods used in this study.

the teacher, peer influences, materials, setting, evaluation criteria and procedures, cultural context, and other such factors.

The nature, quality, and degree of the role played by each factor enhances or reduces learning potential. Just as the weakest link in a chain determines its overall strength, so learning will be limited by the weakest of the sets of factors. Greater learning occurs when a student feels safe and enjoys the challenge and support available from the teacher, rather than in a situation in which one or more of these features is diminished.

The dynamics of good learning events in the ZPD are complex and mysterious. Do these experiences differ for gifted and nongifted individuals and their teachers? Might Kanevsky's model enrich our understanding of factors that contribute to the differences parents and educators experience daily when interacting with gifted learners and their peers?

Dynamically Assessing Learning Potential

Vygotsky (1978) emphasized the careful selection of methods used to assess any unit of analysis. Smagorinsky (1995) reiterated this concern: "By choosing a means of assessment, the researcher enters the learning environment with assumptions that a particular means of assessment is capable of determining 'learning'" (p. 203). Vygotsky was acutely aware of the limitations of standardized assessments of independent performance. In order to assess learning prospectively, he proposed learning experiments, or dynamic assessment activities, to create a context in which to examine the knowledge, processes, and collaborations that contribute to good learning. He suggested that, while working with a tutor, a student gains the skills, knowledge, and attitudes needed to solve increasingly difficult problems that the student initially could not have solved alone. Vygotsky's learning experiments in the early 1900s provided a foundation for many contemporary variations of the dynamic assessment techniques. Reviews of these methods can be found in Grigorenko and Sternberg (1998), Kanevsky (2001), Sternberg and Grigorenko (2002), and Swanson and Lussier (2001).

The "graduated prompt" approach to dynamic assessment methods used in some studies tracks the extent of teaching needed for learning and transfer to occur (e.g., Brown & Ferrara, 1985; Campione, 1989; Kanevsky 1994). The amount and nature of assistance has been consistently negatively correlated with traditional measures of intelligence (i.e., the need for the teacher's assistance in the learning sessions diminished as students' test scores rose). For example, when working with average and gifted 7- and 8-year-olds, Kanevsky (1994) found a strong correlation between the amount of support needed to master a pattern-recognition strategy and students' percentile rank on the Stanford-Binet Quantitative subscale (r = -.70) and moderate correlations with the Stanford-Binet Vocabulary subscale (r = -.50) and the Raven's Standard Progressive Matrices (r = -.59). These findings tell us that, at most, these intelligence tests accounted for less than 50% of the variance

in the support needed for learning. In plain terms, learning and intelligence are related, but distinct, constructs.

Focusing solely on the tutor's support neglected the reciprocity of contributions to the collaboration in the ZPD. Sternberg and Grigorenko's (2002) characterization of the ZPD makes this clear:

> The ZPD is a construct that exists neither within the individual nor within the social context. It exists only in the interaction between the individual and his or her social context, because it exists only in the individual's social interaction and is created by this interaction. (p. 38)

As a result, our analysis includes the students' comments, as well as the tutors' . Further, the stimulus for students' comments was of interest. Spontaneous, rather than prompted, remarks indicatd the learner's awareness and control of learning. Those in response to a tutor's prompting reflected students' reliance on the tutor for control of the learning process.

The Factors and Their Measurement

The credibility of any model depends on its ability to account for differences in the phenomenon it claims to explain. As this was the first attempt to validate the model, we chose to limit the scope of this study to the three sets of intellectual factors of learning potential. If our results showed promise, future work would address the full model. No assessment technique exists that would enable us to collect data on all three from one set of learning tasks, so we chose to begin with a collection of procedures. The specific instruments employed appear on Figure 1 with the factor that each intended to measure. More extensive descriptions are provided later in the "Instruments and Procedures" section.

General Knowledge Base. A learner's knowledge base includes the repertoire of facts, concepts, skills, and strategies that can be used appropriately without assistance. Traditional intelligence and achievement tests tap these resources and provide retrospective estimates of knowledge and skill development already completed. Thus, as the examinee is given no assistance, test scores indicate the current status of development related to the content of the items.

Information Processing Efficiency. All abilities and capacities related to the perception, storage, retrieval, and manipulation of

information drawn from the environment and knowledge base are included here. To measure two elements in this set, we drew on the ideas of Alexander Luria, Vygotsky's student and then colleague. We believe that ours is the first study to examine the relationship between constructs and methods proposed by these two members of the famous Russian *troika*.

Luria (1966) described two functionally independent dimensions of encoding: successive and simultaneous synthesis. *Successive synthesis* occurs when bits of information are consecutively connected. "Each link integrated into a series can evoke only a particular chain of successive links following each other in serial order" (Luria, p. 77). For example, listening to or singing a melody involves successive synthesis. The melody is a sequence of notes and must be processed in a particular order. *Simultaneous synthesis* refers to the organization of information into quasi-spatial arrangements. Here the interconnections between elements of information are paramount, not the order. Drawing a map, understanding place value in arithmetic, or solving a geometry problem are examples of activities requiring simultaneous synthesis. Kirby and Das (1990) suggested that one's capacity to simultaneously synthesize can be interpreted as "the 'size' of the units that can be constructed in working memory" (p. 322). By contrast, the ability to synthesize successively can be interpreted as the capacity of working memory.

Although these two abilities are believed to be independent, both are involved in any complex task to differing degrees. For example, reading text (Kirby & Das, 1990) or listening to music (Geake, 1996) are believed to involve a hierarchy of successive and simultaneous syntheses. With reading, "A sequence of syllables or sounds must be coded (successive) so that a word may be recognized (simultaneous), and then a sequence of words (successive) may be re-coded as a phrase (simultaneous)" (Kirby & Das, p. 326). Low ability on either successive or simultaneous syntheses causes a "bottleneck" for coding to proceed to higher levels. In Kanevsky's model, such a limitation would be expected to reduce learning potential and the breadth of the ZPD.

Metacognitive Knowledge and Control. Information processing requires management via inner-directed attention, or metacognition, for its successful execution. Metacognition determines which information or skill is retrieved from the knowledge base and applied in an activity. It is also active when a learner decides to ask for help. Luria (1973) referred to this third functionally independent

dimension of information processing as *executive synthesis*. These metacognitive skills (e.g., planning, attention, task focus, and cognitive control) comprise the third of the three intellectual factors in Figure 1.

Hypothetically, successive, simultaneous, and executive syntheses would contribute to learning to recognize mathematical patterns like those used in this study in the following ways. When attempting to complete this sequence—2, 5, 10, 17, _, _,*—successive synthesis would enable an individual to keep the given sequence and possible extensions in mind. Simultaneous synthesis is required to investigate the pattern, that is, the possible interrelationships between the terms (e.g., 2 is to 5 as 5 is to 10 as 10 is to 17? or 2 is to 1 as 5 is to 2 as 10 is to 3?). The various aspects of executive synthesis are used to stay on task, to monitor progress, to plan the generation of alternate solutions, and finally to choose a preferred answer.*

In previous studies, tests based on Luria's model of information processing have been useful in the identification of intellectually gifted children (Geake, 1994; Karnes & McCallum, 1983; Schofield & Ashman, 1987). Gifted children typically have significantly higher abilities on simultaneous and executive syntheses. Although the relative strengths of cognitive abilities are stable with age, the use children make of these abilities changes with cognitive development. Very young children rely most on successive processing. Formal school learning usually involves an increasing use of simultaneous and executive processing. Success in high school subjects, such as math, science, computing, and English, is increasingly dependent on simultaneous processing ability due to the increasing emphasis on understanding relationships (e.g., laws in physics, subtext, and character in English), rather than isolated facts.

In this study, we investigated differences in the contributions of general knowledge, information processing efficiency and metacognition to the learning potential of gifted and nongifted students. First, we looked for differences in the performances of gifted and nongifted students on measures of intellectual factors and learning potential. Relationships among the results of these assessments were then investigated to test the interdependence of these factors indicated by the overlapping regions in Kanevsky's model. We sought a small sample on which to test our methods and model in order to determine their validity and worthiness for subsequent studies.

*Possible solutions to 2, 5, 10, 17, ___, ___: Each number increases by the next odd integer, or prime number. Two possible correct sets of numbers to go in the two blanks would be either 26, 37 (odd numbers) or 28, 41 (primes).

Methods

Participants

Initially, 36 students completed four static and six information processing tests (see "Instruments" section). All attended the same Canadian, suburban, public elementary school. Twenty-five students were selected to participate in the dynamic assessment sessions because they had scored above the 50th percentile on the Vocabulary subtest of the Stanford-Binet Test of Intelligence IV (SBV). Twelve of the 25 were girls and 13 were boys. Their ages ranged from 8 years 10 months to 10 years 1 month. The 11 students not included in the dynamic assessment sessions had scored below the 50th percentile on the SBV or were absent. The 50th percentile was used as a cutoff point to set a tougher standard of comparison with the gifted group than one would find in studies that included students with a broader range of SBV scores (i.e., it would be easier to find differences if the comparison group included students from lower percentiles).

The 25 students were intentionally, although loosely, stratified based on the results of the SBV to ensure the data analysis would involve sufficient numbers of students across the distribution above the 50th percentile. The SBV percentile was used as the criterion for stratifying the sample because it had the greatest loading on *g*, or a general intelligence in factor analyses (Thorndike, Hagen, & Sattler, 1986). A minimum of 3 and maximum of 8 students represented each 10-percentile-point range above the 50th percentile. Four scored above the 90th, 3 were in the 80s, 7 in the 70s, 8 in the 60s, and 3 in the 50s.

A child was considered gifted if he or she scored at or above the 87th percentile on the SBV *and* earned a score greater than .60 on either of the components representing simultaneous or executive synthesis on the Luria information processing battery. These components were included as grouping criteria based on Schofield and Ashman's (1987) finding that gifted children have higher abilities on simultaneous and executive syntheses when compared with nongifted children. Five students formed the gifted group as a result of satisfying both the SBV and component criteria. The remaining 20 formed the nongifted group.

Instruments and Procedures

Participants completed two batteries of tests. The first four assessed features of children's general knowledge base:

1. The Stanford-Binet IV vocabulary subtest (SBV) provided an index of verbal comprehension (Thorndike et al., 1986).
2. The Stanford-Binet IV quantitative reasoning subtest (SBQ) provided an estimate of mathematical reasoning ability.
3. The Raven's Standard Progressive Matrices assessed visual pattern-recognition ability.
4. A 40-item test assessed the students' knowledge of basic math facts.

Raw scores on the first three instruments were converted to percentiles for the data analysis. The fourth score was the number of items correct on the math-facts quiz. Items on the quiz assessed the single and double-digit addition and subtraction skills essential to success in the mathematical pattern-recognition problems used in the dynamic assessment. The SBV and SBQ were administered individually; the Raven's and a test of math facts were given individually or in small groups.

A second set of measures, the Fitzgerald Computer-Adaptive Information-Processing Ability Test Battery (Geake & Fitzgerald, 1995), consisted of six computer-based adaptive marker tests, two for each of the three dimensions in Luria's model (see Appendix A). Successive synthesis abilities were assessed by the Word and Number Span tests, which measured the extent of students' recall of lists of words and numbers. Simultaneous synthesis ability was assessed using the Inverted Matrices and Paper Folding tests. Executive synthesis was assessed by two attention tasks: Size and Number/Letter. The first was a Stroop-type test of the words *large* and *small* written in large- or small-size fonts. The second was a recall of either letters or numbers from a mixed set. Students worked individually at their own computers.

All of the Luria tests were completed under timed conditions with unlimited practice. Item difficulty was determined adaptively. The adaptive format worked in the following way. Test items were selected "live" from a database of previously normed and difficulty-rated items. The level of difficulty of each item depended on the student's success or failure on the previous item. For example, if a subject succeeded on an item, the next item was chosen to be more difficult. The highest level of difficulty at which the student made three consecutive correct responses determined his or her score. A strength of the adaptive format employed in this study was its recognition of student learning while testing, thus its conceptual compatibility with the dynamic assessment regimen. Subject scores were determined by reliability estimation (i.e., the best a child could do, rather than the number of correct responses).

Each of the 25 students scoring above the 50th percentile on the SBV participated in dynamic assessment sessions. The tutor was blind to students' scores on any of the earlier measures. In the sessions, students completed 16 increasingly difficult mathematical pattern-recognition problems (see Appendix B) with the support of the tutor, one-to-one, in what Sternberg and Grigorenko (2002) have called a *cake format*:

> In the cake format, the number of layers of the cake is almost always varied (i.e., the amount of feedback depends on how quickly the examinee is able to use the format to reach a correct solution). The contents of the layers, however (i.e., the type of feedback), may or may not be constant. Most often, they are constant: The number of hints varies across examinees, but not the content of them. (p. 27)

The first author, Kanevsky, was the tutor in the dynamic assessment sessions. She has 4 years of classroom experience with students the age of the participants in this study, an undergraduate degree in psychology, and three graduate degrees in the education of gifted students. She was also responsible for the development of dynamic assessment tasks and procedures over the preceding 10 years.

For several reasons, mathematical pattern-recognition tasks were used as the learning problems here. First, they are core curriculum content, so the procedure and results would have implications for classroom learning. Second, while there is a convergent solution, there are a number of paths to a solution. Third, pattern-recognition tasks have been used extensively in studies of mathematical potential. This problem series had been developed and used successfully in earlier research. They were found to offer students of similar age and ability developmentally appropriate challenges (Kanevsky, 1995a). Finally, none of the students completed all of the patterns without assistance, so they afforded a good opportunity to evaluate learning potential.

Problems were presented one at a time in order of increasing difficulty as determined by student performance in pilot tests. Students were assured that the tasks were not a math test; this was a study about learning. They were encouraged to ask for help whenever they felt the need. Interactions while solving the problems were informal and instructive, not scripted.

Students were given extensive "wait time" to develop their own problem-solving strategies and to enable them to work as independently as possible. Assistance was offered when the student asked

for it or was visibly frustrated. The goal of the tutor's assistance was for a student to develop effective, flexible pattern-recognition strategies, not simply to solve each problem. Students were encouraged to transfer what they had learned while solving one puzzle to subsequent puzzles.

These sessions took place in an unused classroom. They ranged from 14 to 56 minutes in length and were videotaped for later analysis. A research assistant transcribed the tapes, and all task-related comments made by the tutor and students were coded using codes developed in earlier studies (Kanevsky, 1994, 1995a). Brief definitions are offered here; more extensive definitions are provided in Appendix C. Supportive instructional hints offered by the tutor were categorized as concrete (e.g., exactly what to do next), cognitive (e.g., a strategy to solve part of the problem), or metacognitive (e.g., a prompt to consider a different plan). Metacognitive prompts were further broken down into those focusing on planning, monitoring, and transfer. Other tutor comments coded were simple offers of help and encouragement to use a counting strategy (e.g., counting on fingers).

Students' comments were coded on two dimensions: (a) according to the nature of their content (planning, monitoring progress, correct or incorrect pattern identified, recognition of similarities across tasks, thinking out loud, and spontaneous requests for feedback) and (b) spontaneous or prompted (a response to a comment from the tutor). Cumulative totals for each code on the 16 tasks were tallied for use in the subsequent descriptive and statistical analyses. The total time taken to complete all of the problems was also computed for each student.

Two research assistants and Kanevsky coded the transcripts. One of the assistants coded the tutor's comments, and the other coded the students'. Kanevsky coded a total of six transcripts for both student and tutor. Initially, three transcripts were randomly selected and coded. Consensus (95% agreement) was achieved on the operational definitions of codes. Three additional transcripts were randomly selected and coded by Kanevsky, the first author. These were checked against the research assistants' coding. Agreement without consensus seeking ranged from 92% to 96%.

Results

Analyses of differences between gifted and nongifted students will be presented first, followed by analyses of the relationships among

the variables. Although our sample and group were small, exploratory statistical analyses were carried out using SPSS. We also realized that our efforts to limit the range of students' ability by including only students of average or above-average ability further reduced the likelihood of finding statistically significant differences between the groups. As a result, we have taken a liberal view of levels of significance by reporting differences up to and occasionally exceeding $p = .10$. We have also avoided generalizing our results. Power analyses were used when interpreting the strength of the relationships among the factors in the model.

Differences in Students' Knowledge Bases

A series of two-tailed *t* tests for groups with unequal variances was used to test the significance of differences in mean test scores of the gifted and nongifted groups (see Table 1). That the gifted group's SBV mean score was significantly higher ($p < .01$) merely reflects its use as a grouping variable. Also, as was expected, the gifted group's mean Raven's score was also significantly higher ($p = .017$). To our surprise, the groups did *not* differ on the SBQ and math facts. With initial equivalence in math knowledge, group differences found in variables tracked during the dynamic assessment sessions could be attributed to differences in learning, rather than prior knowledge.

Differences in Information Processing Abilities

Component Analysis. An initial analysis of the Luria test data was undertaken for the whole group of 36 children to take advantage of the more extensive range of scores. That is, we wanted to maximize the available statistical power and avoid the limited range effect produced by samples of homogeneous or extreme ability (Geake, 1996). A principal components analysis (with Varimax rotation) was employed because the components were constrained to be orthogonal, reflecting the assumption in the Luria model that the three dimensions of information processing and metacognition were independent of each other (see Table 2). The adaptive design of the marker tests removed any ceiling effects.

Component 1, with significant loadings (> .40) from the Word Span (.79) and Number Span (.77) tests, reflects successive synthesis. Component 2, with significant loadings from the Size Attention (.72) and Number/Letter Attention (.73) tests, reflects simultaneous synthesis. Component 3, with a significant loading

Table 1

Means, Standard Deviations, and *t*-Test Results for Age and Static Test Results By Group (*n* = 25)

	Gifted $n = 5$		Nongifted $n = 20$			
	Mean	*SD*	Mean	*SD*	*p*	adjusted *df*
Age (months)	116.6	1.67	115.35	3.96	.297	16.33
Stanford-Binet Vocabulary percentile (SBV)	92.2	3.90	67.75	8.66	.000	15.11
Stanford-Binet Quantitative percentile (SBQ)	59.0	23.63	54.69	25.85	.732	6.63
Raven's percentile	88.0	7.81	73.15	19.63	.017	17.45
Math comp-utation score (number correct of 40 items)	33.8	5.63	35.95	3.28	.452	4.70

from the Inverted Shapes (.93) test, reflects executive synthesis. The failure of the Paper Folding test to load on the same component as the Inverted Matrices, together with the cross-loadings onto Component 1 (-.52) and Component 2 (.59), was unexpected and at odds with instrument validation with children of a similar age (Geake & Fitzgerald, 1995). One explanation is that this task was more difficult for most of the children in this study than it had been for other groups of the same age. The negative loading on successive synthesis may indicate that these children unsuccessfully tried to employ successive synthesis on a task designed to measure simultaneous synthesis (i.e., their abilities on simultaneous synthesis were relatively depressed). With most of the variance being taken up by the component for successive synthesis, this component structure is similar to other samples of slightly younger chil-

Table 2

Principal Component Loadings of Luria Model Marker Tests (N = 36)

	Rotated Factor Matrix		
	Component 1 Successive synthesis	Component 2 Simultaneous synthesis	Component 3 Executive synthesis
Inverted Shapes	.01	.06	.93
Paper Folding	-.52	.59	.15
Word Span	.79	.14	-.13
Number Span	.77	.12	.23
Number/Letter Attention	.28	.73	-.26
Size Attention	.16	.72	.36

dren. Bartlett factor scores were computed for each student for the three components and used for the gifted group selection and to examine group differences in the other measures.

Group Differences. Mean component scores for the gifted and nongifted groups are provided in Table 3. Group differences on the three components were tested for significance using two-tailed students t tests for groups with unequal variances. As was found in the SBV t-test results, the significant difference in mean component scores on simultaneous synthesis (p = .083) merely confirmed that this selection criterion did, in fact, create distinct groups. It is worth noting, however, that the probability levels for successive synthesis (p = .117) and on executive synthesis (p = .141) approached significance. This was expected due to the gifted group's large, positive simultaneous and executive synthesis component scores. Interestingly, the mean component scores for the nongifted group on simultaneous synthesis were depressed; a possible interpretation of this result will be discussed later.

Differences in Comments During the Dynamic Assessment Sessions

Again, students' t tests were used to compare the means of the totals of the coded variables from the transcriptions of conversations dur-

Table 3

Means and Standard Deviations for the Luria Model Component Scores by Group

	Gifted $n = 5$		Nongifted $n = 20$			
	Mean	*SD*	Mean	*SD*	*p*	adjusted *df**
Component scores						
Successive synthesis	-.48	.57	.09	.98	.117	10.82
Simultaneous synthesis	.67	1.04	-.40	.89	.083	5.56
Executive synthesis	.63	.67	.02	1.06	.141	9.81

*The extent to which the degrees of freedom is adjusted downwards in SPSS provides an indication of the degree to which the assumption of equal variance was violated.

ing the dynamic assessment session. Table 4 provides group means, standard deviations, and levels of significance for tutor comments. Table 5 provides the same information for student comments. Statistically significant group differences in the means were found on 4 of the 8 types of tutor comments and 6 of the 11 types of student comments. The groups' means for total time needed to complete the problems appeared different (gifted m = 26:0 minutes, sd = 8.8; nongifted m = 32.4 minutes, sd = 10.4), but the difference did not achieve statistical significance, likely due to the small sample sizes.

Gifted and nongifted students' interactions with the tutor differed in several ways while they learned to complete the number patterns. Students in the gifted group needed

- fewer prompts to monitor their progress,
- no prompts to transfer (apply strategies used in earlier problems),
- less cognitive support overall (a strategy for solving some part of the problem), and

Table 4

Means, Standard Deviations, and *t*-Test Results for the Tutor's Comments During the Mathematical Pattern-Recognition Lessons

	Gifted $n = 5$		Nongifted $n = 20$			
	Mean	*SD*	Mean	*SD*	*p*	adjusted *df*
Metacognitive support						
- planning	3.20	2.86	3.15	2.52	.973	5.65
- monitoring	4.80	2.39	8.65	3.95	.019	10.33
- near transfer	0.40	0.89	0.50	0.69	.824	5.25
- far transfer	0.00	0.00	0.45	0.61	.004	19.00
Cognitive support	10.60	6.61	19.45	12.91	.052	12.80
Concrete support	25.20	15.61	52.15	29.17	.015	12.06
Offers of help	2.80	1.30	2.50	1.82	.684	8.43
Counting strategy	4.00	2.65	3.10	1.77	.503	4.94

- less concrete support overall (direction on exactly what to do next).

As indicated in Table 5, students in the gifted group

- made fewer spontaneous or prompted comments about their plan for solving the problem, an alternative path to a solution, or having finished;
- made fewer spontaneous comments monitoring their successes or difficulties or correcting themselves;
- spontaneously described their thinking less often;
- shared their thinking less often after being asked to explain it; and
- made fewer requests for feedback on their strategy or computations.

Other differences that came close to achieving significance ($p < .13$) indicated that students in the gifted group

- made fewer comments about monitoring their progress after being prompted to do so,

Table 5

Means, Standard Deviations and *t*-Test Results for Students' Comments and Time Used During Learning Sessions

	Gifted $n = 5$		Nongifted $n = 20$			
	Mean	*SD*	Mean	*SD*	*p*	adjusted *df*
Spontaneous student comments						
Planning	.80	1.79	3.40	4.95	.072	19.16
Monitoring	3.80	4.82	13.25	13.21	.018	19.02
Pattern recognition	3.40	3.29	5.40	3.35	.269	6.25
Recognizing similarities	2.20	1.64	3.75	2.27	.119	8.32
Thinking out loud	2.00	2.83	7.10	11.63	.091	22.95
Requests for feedback	7.00	3.67	13.50	12.28	.055	21.78
Prompted student comments						
Planning	.00	.00	.35	.81	.069	19.00
Monitoring	.80	.84	1.80	2.24	.126	18.59
Pattern recognition	14.60	3.85	11.00	3.42	.107	5.69
Recognizing similarities	.60	.89	.20	.52	.384	4.71
Thinking out loud	3.40	2.51	6.50	5.43	.081	14.63

- identified more patterns correctly after prompting, and
- commented on similarities in the puzzle tasks less often.

In summary, the dynamic assessment procedure provided evidence of both quantitative and qualitative differences in gifted and nongifted students' learning. The gifted group spoke less and needed less assistance. They also preferred to generate solutions independently, self-regulate their learning, and monitor their own progress. Gifted students' relatively higher Luria component scores for executive synthesis offer further evidence that these differences could be, at least partly, attributable to differences in metacognitive abilities.

Relationships Between Learning Potential and Knowledge

Correlations between the comment variables from the dynamic assessment of learning potential and students' scores on the knowledge tests were surprisingly low (see Table 6). In previous studies mentioned earlier, the correlations between the amount of assistance (total hints) and intelligence test scores have been up to r = .70. Here it was only r = .34 and barely significant (p = .102). The only correlations between hints or student comments and the SBV greater than .33 were with the number of concrete hints and self-monitoring, both of which were negative. This indicates students in higher SBV percentiles needed less direction and talked to themselves less about their progress, a finding consistent with the group differences reported above.

The number of times students were encouraged to use a counting strategy was moderately and positively correlated with SBQ percentile ranks (r = .53). This means that the likelihood a student would be offered this type of hint rose with SBQ percentile. This suggests that the reminder to use their fingers or a tally corrected the difficulties high-SBQ students had completing the patterns. The earlier comparative analysis of hint use indicated nongifted students needed more strategic hints and concrete direction. It is likely that their reliance on this assistance reduced their need for prompts to use a counting strategy.

There was a slight negative correlation between Raven's scores and the number of requests for feedback (r = -.34). As students' ability to complete the visual patterns in the Raven's rose, they tended to ask for less feedback. The strength of the inverse relationship between the Raven's and number pattern completion was even greater when transfer-related comments were examined. The higher a student's score on the Raven's, the smaller the likelihood that he or she would comment on similarities in the strategy he or she used to solve subsequent tasks. This comment may have been made internally, but it was not shared with the tutor.

If learning potential were synonymous with the constructs underlying any of these traditional measures of independent performance, we would have seen consistent, strong correlations. We did not. It may be that the measures of autonomous and assisted performance tap related constructs, but the immaturity of information-processing abilities and basic math skills of the participants in this study has resulted in the findings reported here.

Total time was highly correlated with the total number of hints students used on the 16 problems (r = .74), indicating that children who were more dependent on the tutor also needed more time.

Table 6

Correlations Between Dynamic Assessment Variables AND Test Scores

	SBV	SBQ	Raven's	Math facts
Tutor Comments				
Monitoring	-.17	-.27	-.12	.01
Planning	.27	-.03	-.26	.25
Far transfer	-.06	.20	.02	.01
Cognitive hint	-.30	-.04	-.12	.11
Concrete hint	-.40**	.13	-.21	.01
Counting strategy	-.00	.53***	-.13	-.16
Offer of help	-.08	.14	-.28	-.17
Student Comments				
Self-monitoring	-.43	-.33*	-.17	-.06
Request for feedback	-.23	-.14	-.34*	.18
Similarities	.07	-.27	-.57***	.24

*Correlation is significant between the .10 and .05 levels (two-tailed).
**Correlation is significant between the .05 and .01 levels (two-tailed).
***Correlation is significant at the .01 level or less (two-tailed).

Subsequent analyses will shed light on how they were using that time.

Relationships Among Knowledge, Information Processing, and Metacognition

Pearson product moment correlations were computed to determine the strength of the relationships between pairs of variables that operationally defined the three factors in intellectual potential in Kanevsky's model (see Table 7). We used power analyses to interpret the results due to the restricted range of ability in the sample. For our sample size of 25, mild correlations of $r = .33$ were significant at the $p = .10$ level; moderate correlations of $r = .40$ were significant at the $p = .05$ level; and strong correlations of $r = .50$ were significant at the $p = .01$ level.

Two correlations surpassed 10% of explained variance: math facts with successive synthesis ($r = .40$) and SBQ with simultaneous

Table 7

Correlations Between Luria Test Component Scores and Static Measures (*n* = 25)

	SBV	SBQ	Raven's	Math facts
Information processing				
Successive synthesis	-.16	.01	.30	.40*
Simultaneous synthesis	.14	.44**	-.14	.02
Metacognition				
Executive synthesis	.19	.03	.24	-.25

*Correlation is significant between the .10 and .05 levels (two-tailed).
**Correlation is significant between the .05 and .01 levels (two-tailed).

synthesis (r = .43). The latter relationship is consistent with previous studies using the Luria model (e.g., Das, Naglieri, & Kirby, 1994). The former relationship could indicate that, for these students, basic math skill was more reliant on successive encoding strategies, such as recall and use of algorithms, rather than on such simultaneous encoding strategies as pattern recognition. This interpretation is consistent with the cognitive immaturity previously noted in the component structure. Executive synthesis (metacognition) was not even mildly correlated with any of the knowledge assessments. A possible interpretation is that these students did not rely on such planning or cognitive control processes as chunking or unpacking.

Relationships Between Learning Potential and Information Processing Variables

Pearson product moment correlations were also computed between the tallies of tutor and student comments and the Luria model component scores (see Table 8). All but one of the correlations between simultaneous synthesis and the types of comments were stronger than .33, and most were negative. Simultaneous synthesis was negatively related to the number of prompts to monitor progress, prompts to plan, and cognitive strategy hints offered. This suggested that children with higher abilities on simultaneous synthesis needed less help on the pattern-recognition tasks. The

Table 8

Correlations Between Information Processing and Metacognitive Component Scores and Dynamic Coded Variables (*n* = 25)

	Tutor Comments						
	Monitoring prompt	Far transfer prompt	Planning prompts	Cognitive hints	Concrete hints	Counting strategy prompt	Offers of help
Information processing							
Successive synthesis	.13	.09	-.23	-.01	-.04	-.21	-.39*
Simultaneous synthesis	-.60***	-.31	-.37*	-.49**	-.32	.43**	.27
Metacognition							
Executive synthesis	-.37*	-.02	.08	-.21	-.20	-.11	-.07

	Student Comments		
	Prompted monitoring comment	Request for feedback	Prompted similarities comment
Information processing			
Successive synthesis	-.14	.09	.06
Simultaneous synthesis	-.36**	-.37**	.36**
Metacognition			
Executive synthesis	.00	-.46	-.32

*Correlation is significant between the .10 and .05 levels (two-tailed). **Correlation is significant between the .05 and .01 levels (two-tailed). ***Correlation is significant at the .01 level or less (two-tailed).

strongest correlation was between simultaneous synthesis and monitoring (r = -.60). This indicated that students who could only process small units of information were most frequently reminded to check their work, and vice versa; children who could process larger units were seldom prompted to check. Simultaneous synthesis was moderately positively correlated with prompts to use a counting strategy, indicating that the greater a child's simultaneous synthesis ability, the more likely it was that the tutor encouraged the use of fingers or a tally to help keep count. When considered with the negative correlation of similar strength with cognitive hints, it may be that the idea of using a counting strategy was sufficient for students with high simultaneous synthesis scores, while their peers needed a broader range of strategic support.

Simultaneous synthesis was also negatively correlated with students' responses to the tutor's suggestions that they check their work and requests a student made for the tutor's feedback on the accuracy of their work. This meant that children who were better able to synthesize related information simultaneously spoke to the tutor less about their progress and asked for less feedback.

Simultaneous synthesis was positively correlated with the number of responses children made when encouraged to find similarities in the ways they might complete puzzles in the series. That is, children with greater simultaneous synthesis abilities could talk about what they knew from problems just completed.

Successive synthesis was mildly negatively correlated with the number of times a student was asked if she or he would like help, suggesting that students better able to think about information sequentially were better able to keep a sequential plan in mind. It might also reflect the tutor's awareness of the learner's need for help with developing a plan. It was no surprise that executive synthesis was negatively correlated with the number of times the tutor prompted the student to monitor his or her work and the number of times a student requested feedback on his or her progress. That is, children who were more capable of monitoring their own learning were less reliant on the tutor.

Discussion

The purpose of this study was to explore the ZPD by investigating the contributions of the intellectual factors in Kanevsky's model of learning potential by (a) testing each factor's ability to distinguish students expected to have more and less learning potential and (b)

determining the strength of the relationships between the factors and learning potential. Overall, the results provide encouraging evidence of the relationships among the intellectual factors proposed in Kanevsky's model. The statistically significant differences and relationships are valid for this small sample, but should not be generalized beyond it. Clearly, a larger sample with a broader range of ability would have provided a stronger test and may do so in the future.

Membership in the gifted group was determined by conventionally partitioning SBV and simultaneous synthesis scores. Gifted students also earned a higher mean score on the Raven's, another traditional measure. The mean difference in *g* between the two groups as indicated by the SBV scores suggested that we could expect the differences in the breadth of their ZPDs. To some extent, our use of traditional achievement and ability tests for the selection of an experimental group representing gifted students may be a self-referential limitation to the results. Obvious and more serious limitations to the generalizability of our findings are the small sample size and restricted range of ability in the sample.

To our amazement, we found ourselves with groups of gifted and nongifted students with equivalent knowledge of math facts and reasoning. This was an asset in a study of children's learning potential where prior knowledge would otherwise have had to be a covariate. It gave us a strong base on which to claim that differences in the groups' performances on the number pattern problems were indicative of ability-related differences in learning potential. Understanding this baseline similarity is difficult in light of all of the differences we found in learning potential. It is likely that these students simply had not had opportunities to learn to solve problems like those on the SBQ in a supportive context. In many other respects, the gifted children were much like their peers in previous studies, for example, higher Raven's, lower hint totals, and so forth (Brown & Ferrara, 1985; Kanevsky, 1990, 1994, 1995a). With group equivalence in quantitative knowledge base as a starting point, the group differences in the information processing and dynamic assessment variables are even more informative. If the gifted children were using different information-processing abilities on the Luria tests, it is likely they also used these capacities differently while learning. This may underlie differences in the ZPDs evident in the nature of their conversations in the dynamic assessment sessions.

A second unexpected finding arose in response to the question of group differences in information processing and metacognition. In

several previous studies, academically gifted students of a similar age have been characterized by high abilities in executive and simultaneous synthesis (Geake, 1994; Karnes & McCallum, 1983; Schofield & Ashman, 1987). In the present study, the gifted students were consistent with their gifted peers only in terms of their significantly higher scores for simultaneous synthesis when compared with their nongifted peers. Unlike previous studies, the superiority of the gifted group on measures of executive synthesis did not reach statistical significance. This result was likely due to the intentionally restricted range of children's intellectual ability in our sample. Moreover, the majority of students in this study were characterized by their dependence on successive synthesis for one of the simultaneous-dependent tasks, as would be expected of their younger peers (Geake & Fitzgerald, 1995). Our results suggest that this sample had not achieved the cognitive maturity of their agemates in other studies. However, in this respect, our sample might not be such an isolated case. In an earlier Australian study of mathematical learning of similar elementary school children, Crawford (1986) reported that

> There are indications that, at the elementary level, school socialization discourages autonomous learning behaviors and places an undue emphasis on imitative modes of learning directed at the mastery of specific operational skills. Students, in the classes studied, were given little opportunity for experience in collaborative problem solving. That is, the social context of the classroom encourages the use of successive processing rather than simultaneous processing. (p. 270)

When reviewing the videotapes and transcripts, quantitative and qualitative differences in learning were evident in the nature and extent of conversations during the dynamic assessment sessions. All of the students appreciated the tutor's availability, but the gifted students were more efficient learners. They were more likely to check their work and needed much less direction. Nongifted students talked about their plans and progress much more often as a means of eliciting feedback and encouragement from the tutor. In contrast, the gifted students valued and sought an independent solution and grudgingly accepted help. This contributed to more visible displays of self-satisfaction when completing the most difficult patterns with minimal help.

Differences in the gifted and nongifted students' need for support in the dynamic assessment sessions were clear and consistent with previous research (Kanevsky, 1994, 1995a). The gifted students

needed less metacognitive, cognitive, and concrete help to complete number patterns and to learn to solve them. In an earlier study, Kanevsky (1990) found that gifted children employ more efficient approaches to information encoding, are able to verbalize task requirements more easily, and make better use of prior knowledge. This ability to transfer was commonly used as an index of breadth of the ZPD (e.g., Brown & Ferrara, 1985).

Our analysis of students' contributions to conversations in the dynamic assessment sessions indicated that the groups distinguished themselves in a manner consistent with the gradual process of internalizing higher psychological functions described by Vygotsky (1978). This was particularly intriguing in light of the groups' equivalence on the tests of quantitative reasoning and basic math computation. Students who had internalized a pattern-seeking strategy no longer needed external support from a tutor, nor did they talk about it. They engaged in less conversation than those in the early stages of developing a solution strategy. If the problems had been at or behind their current level of development, they would have completed all of the math patterns without assistance, but this was not the case. Apparently the gifted students internalized some, but not all, of the necessary elements of the strategy earlier in the series of problems. On average, they worked more autonomously and quietly at a more sophisticated, advanced level. More of their planning and monitoring was internal and private. The nongifted students were more social in their efforts to find the patterns and needed more help. Their reliance on the tutor for external guidance and monitoring is an indication that they were developing their pattern-recognition skills with the support or the tutor. Gradually, this scaffolding was internalized.

It is likely that the tutor's commitment to extended "wait time" enhanced the differences in students' spontaneous comments, as it gave the gifted students the time they needed to develop their own strategies, rather than relying on the tutor. Wait time is also likely the reason that the group differences in total time did not achieve significance. Gifted students used more of the time to think than to talk, while the opposite was true for their peers.

Of Luria's three processes, simultaneous synthesis was most strongly related to conversation while working on the math patterns. This provides a pertinent example of Luria's internalized "matrices of community relationships" that characterize simultaneous synthesis (Crawford, 1986, p. 44). These manifested in verbal expressions "in one's own words with due regard for accurate interpretation" (p. 44) and were distinct from statements made with

fidelity to exact wording as characteristic of successive synthesis. The connection between internal information processing and external assistance provides support for these relationships, which are suggested by the overlapping regions in Kanevsky's model. It also provides some evidence that these information-processing abilities contribute to the breadth of the ZPD, particularly ability in simultaneous synthesis.

The present data can be accounted for by the general positions of Vygotsky, Luria, and Kanevsky on the complexity of learning potential, as well as the salience of internal functions and the social context during learning. For Luria, the development of processes that govern the purposeful direction of attention, and the development of language for informational encoding, occur during childhood. They evolve in the ZPD and are determined by the social mediations described by Vygotsky.

What Did We Learn About Doing This Kind of Research?

It has been said many times, "Only simple questions have simple answers." Finding quasi-experimental support for a complex model is not, in itself, simple. There were many assumptions and operational decisions twixt cup and lip. Nevertheless, our data, such as they are, do offer support for the core of Kanevsky's model where intellectual potential emerges from interaction of information-processing efficiency, general knowledge base, and metacognitive knowledge and control.

Validating a model is a process that cannot be completed in a single study. We've learned about the challenges involved in integrating methods and results. The more time and effort we put into studying a human ability, like learning, the more mystifying it becomes. Idiosyncrasies in the ways individuals learn are evident from task to task and will continue to confound efforts to determine universal relationships among a limited number of variables proposed to explain it. The tension between the drive to identify universals, while acknowledging individual differences, remains.

In addition to validating the model, this research was undertaken with genuine curiosity about what we might find by using constructs and methods proposed by Vygotsky and Luria to study the complexities of learning. Viewing this sample through any one of the measures would have left us with a much different sense of these children than we gained by blending them. Blending methodologies works particularly well when they have emerged from the same theoretical orientation. Even data from small samples have

merit, although they may not have statistical power or generalizability. With minimal financial support available for large-scale studies, we are challenged to extend knowledge in new ways. Blending methods adds dimensionality to the outcomes of research; however, communicating the results of studies using blended methods is tricky, as the assumptions of all must be respected. The crisp, clear lines on the shapes in Kanevsky's model are deceiving. They suggest simplicity, although the research required to validate it must ultimately reflect the perplexing tangle of relationships between, within, and across variables. We leave this endeavor humbled by the experience and with an enhanced appreciation for the work yet to be done.

Why Does This Study Combine Statistics and Qualitative Analysis?

The nature of the inter- and intraindividual processes and constructs involved in learning and development defy representation or analysis in purely qualitative or statistical terms. Whereas low statistical power is an acknowledged limitation, a strength of our study is that, by employing a biparadigmatic approach incorporating statistics and observations, we were able to (re)combine the insightful contributions of Luria and Vygotsky to gifted education for the first time. The power of Vygotsky's ideas is in their complexity, not their simplicity; the whole *is* greater than the sum of the parts. The ZPD has qualities that can and cannot be investigated quantitatively. Its breadth has been analyzed in terms of the extent of assistance or number of tasks used before a student achieves mastery and can flexibly apply a skill. Analyzing and interpreting significant features of social interactions is not as clean. Some aspects are verbal; others are fleeting gestures, postures, facial expressions, and so on. A tutor's smile in one session acts as a silent welcome; in another, it is encouragement to persist. Simply comparing numbers of observable behaviors diminishes their meaning and contribution to the episode.

The growing sophistication of data collection, analysis, and interpretation techniques will enable future researchers to make increasingly better matches between the questions and constructs driving their research and their designs, data, analyses, and interpretations. The art of research is in achieving integrity and fidelity among its elements. We faced these difficult decisions and made our choices, always aware of the limitations imposed by each.

Recommendations to Researchers Intending to Use Dynamic Assessment With Gifted Students

As more conceptions of giftedness take on developmental (e.g., Gagné, 1991) and dynamic features (Tannenbaum, 1997), researchers' and educators' assessment techniques need to reflect the shift away from tracking the development of giftedness as a single state, trait, or capacity. This is not a new message. Vygotsky (1978) raised the "Problem of Methods" as it related to the notion of the unit of analysis early in the 20th century. Before committing to an assessment technique, an educator or researcher must match his or her method to the unit of interest. If the unit of interest is what *has been* learned, assess prior knowledge. If the unit of interest is what *can be* learned, analyze the learning process while learning. Each assessment method intentionally provides different information. Traditional tests of individual performance will continue to serve as a means of establishing a baseline for students' current levels of understanding, but they do not indicate the nature of the learning experience best suited to their future learning and development.

First and foremost, we advise researchers to be true to their beliefs about learning. Selecting or designing an assessment or testing procedure based on the theory of learning and development that is consistent with your beliefs will tap the potentials of interest. There are many different approaches to dynamic assessment that have evolved from different theoretical orientations. For example, Feuerstein's (1979) Learning Potential Assessment Device is based on his theory of learning as cognitive modifiability, while Brown and Ferrara's (1985) graduated prompt methods reflect the influences of sociocultural and information processing perspectives on the learning process.

Other recommendations include the following:

- Remain blind to any achievement and ability test results until all dynamic assessment sessions are complete. This will not only minimize the threat of biasing your results, but it will maximize the suspense. Part of the fun is discovering unexpected talents.
- Provide extended wait time (10 seconds or more) while students are learning. Do more listening and observing than talking.
- Pilot test learning activities with gifted students and be passionate about them to ensure that the ceiling is high enough. Never underestimate the leaps bright, interested students can make when given appropriate support.

- Collect your own data to enhance the accuracy of your interpretations of the students' gestures, pauses, sighs, and so on.
- Always seek peak, independent performances. Optimize the ZPD in everything done and said in the sessions. Reduce stress with smiles and encourage students to guess before offering assistance. Some have learned to rely on teachers more than needed.
- Encourage transfer of learning from one problem to the next and learning from "mistakes."

Dynamic analyses of learning in a social context activate the full model of learning potential as proposed here. They enable researchers and teachers to explore and understand their role in the ZPD. As Grigorenko and Sternberg (1998) concluded, the potential of dynamic assessment has yet to be fully realized. Future research will also be needed to involve the nonintellectual factors in the model, as they were not considered here. For example, in Swanson and Lussier's (2001) meta-analysis of 30 dynamic assessment studies, effect sizes varied as a function of a range of factors, including subject age, assessment procedure (e.g., scripted vs. nonscripted), learning disability, and general ability. Interestingly for gifted education, a larger effect size was found in studies of underachieving students. New assessment and research methods are evolving constantly (for a comprehensive review, see Sternberg & Grigorenko, 2002) and will provide further insights into the dimensions of learning included in Vygotsky's theory and Kanevsky's model. They must be used wisely, acknowledging the purpose, strengths, and limitations of each.

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Authors' Note

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Appendix A
The Fitzgerald Computer-Adaptive Information Processing Abilities Test Battery

The battery consists of the Inverted Shapes Recall Test and Paper Folding Test as marker tests for simultaneous synthesis; Word Span Recall Test and Number Span Recall Test as marker tests for successive synthesis; and Number/Letter Attention Test and Size Attention Test as Stroop-type marker tests for executive synthesis. All tests are taken under timed conditions. Responses are made by using the mouse. Each test is preceded by examples and practice sessions with feedback on correct responses.

Inverted Shapes Recall Test

In this task, subjects have to choose from a set of five lures, which is a target shape inverted by a rotation through 180 degrees. The computer graphic shapes are closed figures that can be drawn on paper by joining some of the dots on either a 3 x 3 or 4 x 4 dot matrix. A target shape is shown to the subject for 1 second. This is immediately followed by 15 seconds response time for subjects to select the inverted target. There are 15 items in all.

Paper Folding Test

Computer graphics indicate how a sheet of paper has been folded two or three times and then has had a hole or holes punched through the folded portion. The task is to choose which one of five lures represents the pattern of holes of the unfolded paper. Twenty seconds are allowed for each response. There are 15 items.

Word Span Test

This task tests the ability to recall sequences of words. A set of words is presented on the screen one at a time. The whole set is then presented with the words in a random order. Subjects are instructed to place the words in the original order of presentation.

Twenty seconds are allowed for each response. The sets are 3 to 13 words long. The length of the set for any particular item is determined adaptively by the subject's responses to previous items.

Number Span Test
This task is identical to the Word Span Test, except that sets of numbers are used.

Number/Letter Attention Test
This task is identical to the Number Span Test, except that mixed sets of numbers and letters are used. Subjects have to reorder either the numbers or the letters as indicated before the set is presented. The sets are 5 to 15 characters long.

Size Attention Test
This is a Stroop-type test for letter size with the words *small* and *large* written in small or large fonts. Subjects are instructed to attend to either the words or their size. Mixed sets of small, small, large, and large are 3 to 13 words long.

Appendix B
Mathematical Pattern-Recognition Problems

a) 10, 20, 30, __, 50, 60, 70, 80, 90
b) 1, 3, 5, __, 9, 11, __, 15, 17
c) __, __, 20, __, 14, __, 8, 5, 2
d) 3, __, __, 15, __, 23, 27, 31, 35
e) 7, __, 9, 8, __, 10, 13, 12, 15
f) 50, __, 38, __, 26, 20, 14, __, 2
g) 17, 3, __, 6, 15, 9, 14, __
h) 27, 26, 22, __, 17, 16, __, 11, 7
i) 1, 3, 6, 10, 15, 21, __, __, 45
j) 2, 3, 6, 8, 14, __, __, 33, 42
k) 7, 14, 21, 28, __, __, __, __
l) 3, 10, __, 24, 31, 38, __
m) 9, 16, 23, 30, 37, __, __
n) 2, 4, 8, __, 32, 64, ___
o) 3, 5, 9, __, 33, 65, __
p) 5, 7, 11, 19, __, 67, __

Appendix C
Codes for Content Analysis of Comments

Tutor Codes

Metacognitive supports: how to think about thinking in these activities.

> **Planning**: Questions that focused on student's orientation to the problem at the global level (e.g., "Where is the best place to start?" "What needs to be done next?" "Do you have enough information?").
>
> **Monitoring**: Encouragement to monitor the success of the current approach, check their calculations, or extend the pattern to the end of the puzzle to check it (e.g., "How well is that working out for you?").
>
> **Transfer**: A comment that encouraged student to use or refer back to experience with a part of the current puzzle—near transfer—or a previous puzzle—far transfer (e.g., "Is there anything you did on the other puzzles that might help you here?").

Cognitive support (what to think): A support that provided one step in a sequence of steps that described how to recognize a pattern or modeled or suggested what to do next; questions that modeled an appropriate pattern-recognition strategy (e.g., "Let's start at the beginning." "Have you pulled it apart?").

Concrete support (what to do)**:** A support that indicated exactly what to do next or reviewed a step or steps used in a previous puzzle or another part of the same puzzle; contained numbers drawn directly from the puzzle being solved.

Help: Tutor asked if student would like help.

Counting strategy: Tutor suggested or modeled use of a counting strategy (e.g., tally, finger counting).

Student Codes

Planning: A spontaneous or prompted meta(cognitive)-level comment that indicated the student was planning a solution or considering alternative places to start; decisions made about what to do next or task completion.

Monitoring: A spontaneous or prompted comment that indicated the student was monitoring her or his progress (doing well, doing poorly), task difficulty, checking calculations, extending the pattern to the end of the puzzle in order to check it, and student caught a mistake and self-corrected.

Pattern: A spontaneous or prompted comment that indicated recognition of a pattern in the puzzle.

Similarities: A spontaneous or prompted comment that indicated recognition of the similarity in the mathematical pattern, task format or demands, or a comment that indicated the student solved a puzzle in the same manner as a previous puzzle.

Thinking out loud: Student described a series of steps or a strategy for recognizing a pattern, not just a string of numbers.

Feedback: Student requested feedback on a computation or part of a pattern (e.g., "Is this right?").